#### REPORT DOCUMENTATION PAGE

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# Final Report to the Army Research Office

for

# Basic and Applied Research in Electronics and Optics Grant DAAG55-98-1-0080 10 November 1997 – 31 January 2002

Professor Daniel Kleppner, Principal Investigator Research Laboratory of Electronics Massachusetts Institute of Technology

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#### 1. Statement of the Problems Studied

The primary objective of this project is to discover and characterize new electronic and optical devices, and to demonstrate how these may be used in novel and critical applications. Theoretical and experimental progress on photonic band gap structures holds promise for important advances in photonics. Progress in ultrasensitive capacitance spectroscopy, quantum circuit theor, and self-assembly of nanoscale structures can be expected to advance the frontiers of nanotechnology. Studies in ultrafast optics offer new ways to characterize the electronic response of materials. Advancing measuring techniques based on atom optics and coherent atom techniques with Bose-Einstein condensates provide a new frontier for atom manipulation and ultrasensitive measurements.

#### 2. Summary of the Most Important Results

Primary research results from this project include the following:

The optical properties of Bose-Einstein condensate were characterized, leading to the discovery of a new form of superradiance, which became the essential element in the realization of a phase-coherent matter-wave amplifier.

A novel scanning microscope was developed that creates images of the quantum Hall state by sensing charges in the 2D system. The apparatus, operating at 0.3 K, is so sensitive that it can detect single electrons in the 2D layer.

The asymmetric Fano line shape in the Kondo regime was calculated using the slave-boson and Hartree-Frock method.

A novel technique for scaling the output power of femtosecond lasers was developed and demonstrated, and the world's record for the shortest laser pulses ever generated directly from a laser, a duration of 5.5 fs, was achieved.

A new semiconductor alloy was designed that possesses a direct bandgap at optical fiber communication wavelengths.

A novel "dual-hardmask" process was developed, enabling fabrication of channel-dropping filters and similar grating-based optical devices.

It was demonstrated that a semiconductor mirror providing two-photon absorption in a harmonically mode-locked fiber laser introduces a fast intensity-dependant loss that can equalize pulse energies and reduce pulse dropouts.

Interference lithography and spatially-phase-locked e-beam lithography were used to generate integrated Bragg gratings in materials that are not photo-reactive.

#### 3. Listing of Publications and Technical Reports

(a) Papers published in peer-reviewed journals

Cho, K., E. Kaxiras, and J. Joannopoulos, "Theory of Adsorption and Desorption of  $H_2$  Molecules on the Si(I11)-(7x7) Surface," Phys. Rev. Lett. 79, 5078 (1997).

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(b) Papers published in non-peer-reviewed journals or in conference proceedings

Bilinsky, I.P., B.E. Bouma, and J.G. Fujimoto, "Self starting KLM  $Ti:Al_2O_3$  laser using semiconductor doped glass structures," Conference on Lasers and Electro Optics CLEO'98, San Francisco, CA, May 3-8,1998, paper CThC4.

Boppart, S.A., B.E. Bouma, C. Pitris, J.F. Southern, M.E. Brezinski, and J.G. Fujimoto, "Optical coherence tomographic imaging of in vivo cellular dynamics," Technical Digest of the Meeting on Advances in Optical Imaging and Photon Migration (AOIPM'98), Orlando, FL, March 8-11, 1998, paper AMC1, p.76.

Boppart, S.A., J.M. Herrmann, C. Pitris, B.E. Bouma, G. J. Tearney., M.E. Brezinski, J.G. Fujimoto, "Interventional optical coherence tomography for surgical guidance," Conference on Lasers and Electro Optics CLEO'98, San Francisco, CA, May 3-8, 1998, paper CtuL2.

Boppart, S.A., C. Pitris, B.E. Bouma, M.E. Brezinski, and J.G. Fujimoto, "Optical coherence Tomography using femtosecond lasers," XIth International Conference on Ultrafast Phenomena, Garmisch-Partenkirchen, Germany, July 12-17, 1998, paper TuD2.

Cho, S.H., B.E. Bouma, E.P. Ippen, and J.G. Fujimoto, "A 15 MHz, 0.5 MW KLM Ti:Al<sub>2</sub>O<sub>3</sub> laser using multiple pass cavity," Conference on Lasers and Electro-Optics, CLEO'98, San Francisco, CA, May 3-8, 1998, paper CThJ6.

Fujimoto, J.G., "Biomedical imaging using optical coherence tomography," Conference on lasers and Electro-Optics CLEO'98, San Francisco, CA, May 3-8, 1998, (invited) plenary paper JMA3.

Fujimoto, J.G., "Optical coherence tomography for medical imaging and diagnosis," XVI International Conference on Coherent and Nonlinear Optics, (ICONO'98), Moscow, Russia, June 29-July 3, 1998, Paper FB1, Keynote address.

- Fujimoto, J.G., "Optical Coherence Tomography for Biomedical Imaging," First International Conference on Ultrasonic Biomedical Microscanning, Eastwood Park, UK, September 1-4, 1998, Keynote address.
- Fujimoto, J.G., "Biomedical Imaging using Optical Coherence Tomography," Fourth Annual Symposium on Frontiers of Engineering, National Academy of Engineering, Irvine, CA, September 17-19, 1998, invited presentation.
- Fujimoto, J.G., "Biomedical Imaging using Optical Coherence Tomography," 19th Congress of the Japan Laser Surgery and Medicine Society, Tokyo, Japan, September 24-25, 1998, Plenary presentation.
- Herrmann, J.M., C. Pitris, B.E. Bouma, S.A. Boppart, J.G. Fujimoto, and M.E. Brezinski, "Two and three dimensional imaging of normal and osteoarthritic cartilage microstructure with optical coherence tomography," Technical Digest of the Meeting on Advances in Optical Imaging and Photon Migration (AOIPM'98), Orlando, FL, March 8-11, 1998, paper AtuD3, p.182.
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- Lim, K.-Y., D.J. Ripin, G.S. Petrich, L.A. Kolodziejski, E.P. Ippen, M. Mondol, H.I. Smith, P.R. Villeneuve, S. Fan, and J.D. Joannopoulos, "Photonic Bandgap Waveguide Microcavities: Monorails and Air-Bridges," presented at the 17th North American Conference on Molecular Beam Epitaxy, October 4-7, 1998, Pennsylvania State University, PA.
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Pritchard, D.E., M.S. Chapman, T.D. Hammond, D.A. Kokorowski, A. Lenef, R.A. Rubenstein, E.T. Smith, and J. Schmiedmayer. "Atom Interferometers and Atomic Coherence." Paper presented at the Fundamental Problems in Quantum Theory Workshop, August 4-7, 1997, University of Maryland, Baltimore, Maryland, Fortschhr. Phys. 46, 801-808 (1998).

Stenger, J., S. Inouye, D.M. Stamper-Kurn, A.P. Chikkatur, D.E. Pritchard, and W. Ketterle. "Bragg spectroscopy and superradiant Rayleigh scattering in a Bose-Einstein condensate." Proc. Intern. Conf. on Laser Spectroscopy (ICOLS), Innsbruck, eds. D. Leibfried, J. Eschner, F. Schmidt-Kaler, and R. Blatt, World Scientific (1999).

Ketterle, W. and C. Raman. "Collisions at nanokelvin temperatures in Bose-Einstein condensates." Proc. International Conference on the Physics of Electronic and Atomic Collisions (XXI ICPEAC) July 1999, Sendai, Japan.

M. E. Grein, E. R. Thoen, E. M. Koontz, H. A. Haus, L. A. Kolodziejski, and E. P. Ippen, "Stabilization of an active harmonically mode-locked fiber laser using two-photon absorption", Paper presented at the 2000 Conference on Lasers and Electro-Optics, San Francisco, California, May 7-12,2000.

## 4. Listing of Scientific Personnel and Earned Advanced Degrees

### (c) Principal Investigators

Allen, J.

Ashoori, R.

Fujimoto, J.

Haus, H.

Ippen, E.

Joannopoulos, J.

Kastner, M.

Ketterle, W.

Kleppner, D.

Kolozieiski, L.

Mochrie, S.

Pritchard, D.

Smith, H.

Wen, X.

#### (d) Other Personnel

Andrews, M.

Berman, B.

Cho. S.

Chov. H.

Devries, J.

Durfee, D.

Erchak, A.

Ferrera, J.

Goldhaber-Gordon, D.

Holley, J.

Ivanov, D.

Koltonyuk, M.

Lim. K.

Lim. M.

Lumma, D.

Murphy, T.

Patterson, S.

Rubenstein, R.

Stamper-Kurn, D.

Thoen, E.

Wang, Y.

#### (e) Advanced Degrees Earned

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